10/524536
DT05 Rec'd PCT/PTO 14 FEB 2005

A CONTROL METHOD FOR CONTROLLING THE GAS FLOW IN A COMPRESSOR

The field of the invention

The present invention relates to a control method for controlling the gas flow in a compressor in which a volume is expanded during an intake stroke and an introduced volume of gas is compressed and taken out through a non return valve for outflow and/or an operable valve during an evacuation stroke, the compressor having a controllable inlet valve that is pneumatically, hydraulically or electromagnetically operated and that is opened and closed upon basis of a signal from a control system.

This type of compressor, of which there are a plurality of embodiments, but where the piston compressor is the most common one, is often called displacement compressor. In order to take advantage of the invention, the compressor should have a controllable inlet valve. However, it is preferred that the compressor also has a non return valve for inflow that can be turned off, and a controllable outlet valve. The invention provides for a varying need of pressurized gas with a reduced energy consumption and environment affection in relation to known methods.

The invention is applicable to displacement compressors for industrial use, for vehicles and vehicle engines, for fuel cells etc.

The invention can only be put into practice by use of a control system. The software of the control system is decisive for its function. The software that is used for putting the invention into practise can be applied as a part of a larger control system, for example a system for engine operation.

As the piston compressor is the most common displacement compressor, the invention will be described, by way of example, outgoing from its implementation on a piston compressor.

The background of the invention

Displacement compressors, particularly piston compressors, are normally operated with a constant and relatively low number of revolutions per minute. Normally, the inlet valves and the outlet valves are non return valves that have a restraining influence on the gas flow at higher numbers of revolutions per minute.

The flow control is normally performed by letting the compressor start when the pressure in a tank connected thereto falls below a certain level and letting it stop when a certain pressure level has been obtained. Frequent starts and stops will result in a large wear and will be energy consuming.

According to another common type of control, the gas flow to the non return valve for inflow is cut off by means of a closure valve when a certain pressure in a tank connected to the compressor is obtained, while the operation of the compressor is permitted to continue with the cycles without any gas to compress. When the pressure in the tank falls below a certain level the gas flow is once again permitted.

When the need of pressurized gas is not very frequent, the first type of control is the most economical one. When the need is more frequent, the latter type is substantially more economical. However, the closure/opening of the gas flow is relatively slow. This means that a plurality of cycles without compression of any gas will be performed also by the shortest possible cut off. Moreover, a slow closure/opening will result in substantial flow losses. Therefore, the tank and the compressor must be of larger dimension than if the cut off of the gas flow to the compressor could be performed so temporarily as one single cycle. Further, a rapid closure/opening would reduce the flow losses.

The invention results in the gas flow not being restrained as mentioned above in the case of non return valves, and that the flow of air can be cut off/opened rapidly and can be cut off for such a short period as one single cycle. Thereby, the energy consumption and the environ-

mental affection can be reduced in relation to prior methods, as well as the size of the compressor and the tank.

The object of the invention

The object of the invention is to provide a method of controlling the gas flow in a compressor and to avoid the above drawbacks and to provide for varying need of pressurized gas with a more rapid control and with a more even pressure level and, at the same time, a reduced energy consumption and environmental affection in relation to methods of prior art.

Summary of the invention

The object of the invention is achieved by means of a compressor in which a volume is expanded during an intake stroke and in which the introduced volume of gas is compressed and taken out through a non return valve for outflow during an evacuation stroke, the compressor having a controllable inlet valve that is pneumatically, hydraulically or electromagnetically operable and that is opened and closed on basis of a signal from a control system, the control method being characterized in that the inlet valve is kept closed during at least a part of an intake stroke. Further features are shown in the following description and in the patent claims.

Here, compressor is referred to as a displacement compressor, and particularly a piston compressor.

A controllable inlet valve, a controllable outlet valve, a non return valve for inflow, a non return valve for outflow and similar expressions are intended to include also other possible embodiments that uses a larger number of valves of said types of valves.

It is also assumed that a compressor can be constituted by a plurality of compressors, for example a plural cylinder piston compressor by which each cylinder defines an individual piston compressor and by which each individual compressor operates in accordance with the description and the patent claims.

A common feature for displacement compressors is that a volume is expanded during an intake stroke. When the volume is expanded, it is filled with gas, such as air, that flows in through a valve, normally a non return valve. At the end of the intake stroke, a volume that encloses the introduced gas is compressed, and the gas is evacuated through a valve, normally a non return valve. The piston compressor is the most common displacement compressor, and in the piston compressor the volume which is expanded and the volume which is compressed is the same. There are also, for example, rotating displacement compressors where the volume that is expanded is not the same as the volume that is compressed. In a piston compressor, a piston moves inside a cylinder between two dead points, referred to as the upper dead point and the lower dead point respectively. The movement of the piston from the upper dead point to the lower dead point results in a volume being expanded in an intake stroke, as expressed in the preamble of patent claim 1. The piston movement from the lower dead point to the upper dead point results in the introduced volume of gas being compressed and taken out through a non return valve for outflow during an evacuation stroke, as also expressed in the preamble.

Normally, there is a non return valve for inflow and a non return valve for outflow located at the upper dead point. When the piston, during an intake stroke, moves from the upper dead point towards the lower dead point, a volume is expanded between the piston and the upper dead point, said volume being filled with gas during the movement through a non return valve for the inflow. From the lower dead point the piston moves, during an evacuation stroke, towards the upper dead point, the volume between the piston and the upper dead point being compressed. Initially, the enclosed gas has nowhere to go and, accordingly, the pressure increases in the volume that gets increasingly smaller. When the pressure in the enclosed gas is sufficiently higher than the pressure on the other side of the non return valve for outflow, the latter is opened and the gas is evacuated during the continued movement of the

piston towards the upper dead point. An intake stroke followed by an evacuation stroke is here referred to as a cycle. A complete cycle is executed during a complete compressor shaft revolution.

With reference to the above description of the background, important advantages are achieved if a cut off can take part for such a brief period as one single cycle. With the aid of a controllable valve according to the initial definition in the description, one single intake stroke can be executed with a closed inlet valve, and this means that no gas is introduced during the intake stroke. This automatically results in no gas being evacuated during the evacuation stroke. Accordingly, the gas flow is cut off during one cycle. An intake stroke executed with a closed inlet valve is referred to as a closed intake stroke.

In order to be able to put the invented method into practice, controllable valves are required, primarily a controllable inlet valve. However, it is preferred with an embodiment with a controllable outlet valve apart from the already present non return valve for outflow. Controllable valves permit a substantially larger flow of air than is possible with contemporary non return valves in compressors of today. Thereby, a substantially higher number of revolutions per minute can be permitted, making it possible to use smaller piston compressors than today. By also applying a non return valve for inflow together with a gas conduit that can be closed, for example with the aid of mechanical technique based on the fact that a certain quantity of air of a certain pressure has been obtained, a substantial advantage of having an aid function is obtained. An aid function that will work even if the controllable inlet valve and/or outlet valve would have a breakdown. By the use of a controllable inlet valve, the latter can be closed during a complete intake stroke, here referred to as a closed intake stroke, but also during a part of the intake stroke, this part being variable from cycle to cycle. Accordingly, the method according to the present invention relies on a closure of the inlet valve during at least a part of the intake stroke for the purpose of con-

trolling the outflow volume during the evacuation stroke. Further, it is also evident that the closure takes place during the sequence by which an ordinary intake stroke normally would exist, and that the compressor operates with a plurality of subsequent cycles of intake strokes and evacuation strokes.

By means of the characterizing control strategy of the control method, namely to provide for the amount of compressed gas that is needed at each moment by the use of a frequency of cycles with closed intake stroke, in which the frequency varies between 0% and 100% of the number of revolutions per minute, a significantly economical operation is achieved. If, for example, the control system chooses the frequency 0%, then no cycle with closed intake stroke is performed, but the gas will be supplied each revolution, and at the frequency of 100%, each cycle is performed with a closed intake stroke, and at the frequency of 50% a cycle with a closed intake stroke will be performed each second revolution, and at the frequency of 20% a cycle with a closed intake stroke will be performed each fifth revolution, and at the frequency of 10% a cycle with a closed intake stroke will be performed each tenth revolution. Accordingly, a cycle with a closed intake stroke can be performed, for example, each second, each third, each fourth, each fifth revolution etc. During the remaining cycles/revolutions, gas is supplied during the intake stroke. At a frequency between 50% and 100%, a cycle with a closed intake stroke will be directly followed by one, two or more consecutive cycles, a series of consecutive cycles, with closed intake stroke. At, for example, 80% cycles with closed intake stroke, a suitable distribution would be to have one single cycle with normal intake stroke after a continuous series of four cycles with closed intake strokes, and then another continuous series of four cycles with closed intake strokes followed by another single cycle with normal intake stroke etc. In order to keep the pressure level as even as possible in a tank for pressurized gas that is associated to the compressor, and in order to permit the tank to be as small as possible, the control

system should be characterized in that generally the same number of revolutions between each cycle, or each continuous series of cycles with closed intake strokes should be performed. The invention could also be described as a way of providing for the immediate need of compressed gas by using a frequency of cycles with a normal intake stroke, resulting in the same effect.

Another characterizing control strategy of the control method, that advantageously can be combined with the frequency control that has been described above, is to provide for the immediate need of compressed gas by the use of cycles where the controllable valve is closed during a part of the intake stroke as decided by the control system, somewhere along the piston path from its upper dead point to its lower dead point. This part of the intake stroke in question can be varied from cycle to cycle. This advantageous possibility makes it possible to minimize a reservoir for the storage of compressed gas or even to let the reservoir be formed by the conduit that conducts the pressurized gas from the compressor to the equipment in which the gas is to be used. The possibility of having a minimum of storage space for the compressed gas is a result of letting a varying consumption be followed by a substantially simultaneously varying production of generally the same quantity of pressurized gas as the quantity that is consumed at a given moment.

Controllable inlet valves and, possibly, outlet valves permit, thanks to substantially reduced flow losses, a substantially increased flow capacity for a predetermined cubic capacity, the latter being referred to as the inner volume of the cylinder between the two dead points of the piston in a piston compressor. This means that a piston compressor, for example, can be connected to the engine shaft of a vehicle engine, and that the number of revolutions per minute directly, or by means of gear reduction, follow the number of revolutions per minute of the engine. In the case of an embodiment comprising a vehicle, the term gas should be substituted by air. The piston compressor may, for example, be used for the production of pressurized

air to the engine combustion, for the purpose of operating controllable, pneumatically operated valves for the engine and/or the compressor itself, for air-assisted fuel injection, for the break system etc. A characterizing feature is that, by high numbers of revolutions per minute and a large need of compressed air, which is the case by engine operation, the inlet valve can be closed after the piston having reached the lower dead point, resulting in that a larger amount of air to be compressed can be supplied in comparison to the case in which the inlet valve closes before the piston reaches its lower dead point. Another characterizing way of increasing the capacity of the compressor upon engine operation is to connect its conduit for air supply to an existing air conduit to the engine with pressurized air produced by an exhaustion gas turbo or a screw compressor. A connection downstream an existing intercooler would be preferred. A connection to a vehicle engine conduit for air supply, downstream the air filter and upstream any existing throttle, is suitable, even if there is no equipment for compressing the air, since the air has passed the air-cleaning filter.

The aid function described above, particularly useful at engine operation, is also a feature of the invention. It defines a feature that results in a certain capacity for the production of compressed air, or any other gas, always being at hand. The aid function is, as has been mentioned, advantageous upon any breakdown of any controllable valve. But it also results in the possibility of immediately building up an air pressure to be used, for example, for start up, by means of the electric start engine, of an engine with air-assisted fuel injection if there is no remaining pressure in the pressure reservoir or the conduit for the pressurized air. The same applies if there, for example, are controllable valves that are pneumatically operated. When there is a large flow capacity in the non return valves for the inflow and the outflow respectively and there is a controllable, pneumatically, hydraulically or electromagnetically operated closure member arranged by or upstream the non return valve for inflow, the aid func-

tion principle is also a prerequisite for the execution of a frequency of cycles with closed intake stroke, or cycles where the controllable closure member is closed during a part of the intake stroke in question, somewhere on the piston path from its upper dead point to its lower dead point, said part being determined by the control system.

As has been mentioned, the method also comprises an embodiment in which the controllable valve for the outflow also is pneumatically, hydraulically or electromagnetically operable. The method is also characterized in that the controllable outlet valve is opened in connection to a pressure balance being obtained between the gas that is to be evacuated and the gas on the opposite side of the outlet valve. It is important to avoid any contact between the piston and the outlet valve, and therefore the preferred embodiment is characterized in that the outlet valve is opened in a direction from the cylinder, that is in the same direction as the movement direction of the piston during compression and evacuation. If the outlet valve is opened in the opposite direction, that is towards the movement direction of the piston, it has to close sufficiently early to avoid any piston contact. In such cases, a combination of a controllable outlet valve and a non return valve for the outflow of gas is advantageous, and a feature, in order to be able to evacuate an amount of compressed gas that otherwise would remain. A sufficiently slight piston contact when a sufficiently small distance remains to the complete closure of the outlet valve is, however, not detrimental, but can be taken advantage of for a good evacuation. However, this implies that the outlet valve is moved along an access/a direction which is exactly the same as the one of the piston.

From the above description and the following description it is obvious that an electronically based control system with the necessary sensors and other components, including a computer program developed for the specific purpose, is an absolute necessity.

Brief description of the drawings

The invention shall now be described with reference to the only figure 1, which shows an exemplifying, schematic picture of a compressor with a piston.

Detailed description of en embodiment

Fig 1 is an exemplifying, schematic picture that shows a compressor cylinder with a piston 1. The piston is under movement during an intake stroke, and air (or any other gas) is flowing through the open inlet valve 2. The inlet valve 2 and the closed outlet valve 3 are constituted by controllable valves that are pneumatically, hydraulically or electromagnetically operable. A circuit 4 is used for operating the valves 2 and 3. A control unit 5 is operatively connected with the circuit 4 for signal control of the circuit and the valves 2 and 3 that are connected to the circuit. Air that is compressed is transported through the outlet valve 3 and/or a non return valve for the outflow of gas 6 through a conduit 7 to a tank 8. By means of a sensor 9 in the tank 8, which is operatively connected to the control unit 5, the control unit is provided with continuous information about the pressure in the tank. A sensor 10, arranged at a graduated arc 12, mounted on the compressor shaft 11 and operatively connected to the control unit 5, delivers continuous information to the control unit for the calculation of number of revolutions per minute and the piston position in the cylinder 1. The control unit 5 determines when the controllable valves 2 and 3 shall open or close. The compressor shaft 11 is, for example, connected to an electric motor or to an engine in a vehicle (connection not shown). Air supplied via the inlet valve 2 may, preferably, be precompressed by means of, for example, an exhaust gas turbine in a vehicle. Advantageously, air for compression may be taken out downstream an intercooler (connection not shown) that might be present in a vehicle. The non return valve 6 for the outflow and a non return valve 13 for the inflow, equipped with a closure member 14, establishes an aid function. Through a conduit 15 the clo-

sure member 14 is connected to the tank 8. If the pressure in the tank 8 decreases below a predetermined level, the closure member 14 opens, for example by the action of a mechanical spring 16, such that air to be compressed is supplied through the non return valve 13 for the inflow. This aid function means that pressurized air can be reduced to a certain amount while the controllable inlet valve 2 is closed or out of function. This is important in order to make it possible to, at least to some extent, propel a vehicle by means of air-assisted members for, for example, fuel injection or brake systems. If, for example, the controllable valves 2 and 3 are constituted by pneumatically operated valves, and the pressure in the tank 8 is too low for the activation of said valves, the aid function shall be provided such that the pressure in the tank will be sufficient for the activation of the valves 2 and 3 being obtained by means of the spring 16 before the closure member 14 associated to the non return valve 13 for the inflow closes. When the controllable valves 2 and 3 are pneumatically operated valves, there is a conduit for the air (not shown) between the valves and the tank 8. Pressurized air for, for example, the aid system of a vehicle is taken from the tank 8 through a connection 17. For the described aid function only small non return valves 13, 6 are required. The need of a large flow capacity is fulfilled by the controllable valves 2, 3. During compression strokes when the non return valve 13 for the inflow is closed through the action of the closure member 14, the outlet valve 3 shall open upon pressure balance between the air in the tank 8 and the air that is compressed in the cylinder 1. A sensor 18, operatively connected to the control unit 5, registers the cylinder pressure. This pressure is compared, by the control unit, with the pressure in the tank for the purpose of checking that the outlet valve 3 has been activated at a correct angular position of the crank. According to an alternative embodiment of the invention, the small non return valve 6 for the outflow and the controllable outlet valve 3 are replaced by one or more non return valves for the outflow. According to a further embodiment of the

invention, the non return valve 13 for the inflow and the controllable inlet valve 2 are replaced by a large non return valve for the inflow, and the closure member 14 is replaced by a rapid, controllable member that, like the valves 2 and 3, is able to cut off the flow of air to be compressed during such a short time as one single cycle.